Nanostructured Materials by Machining

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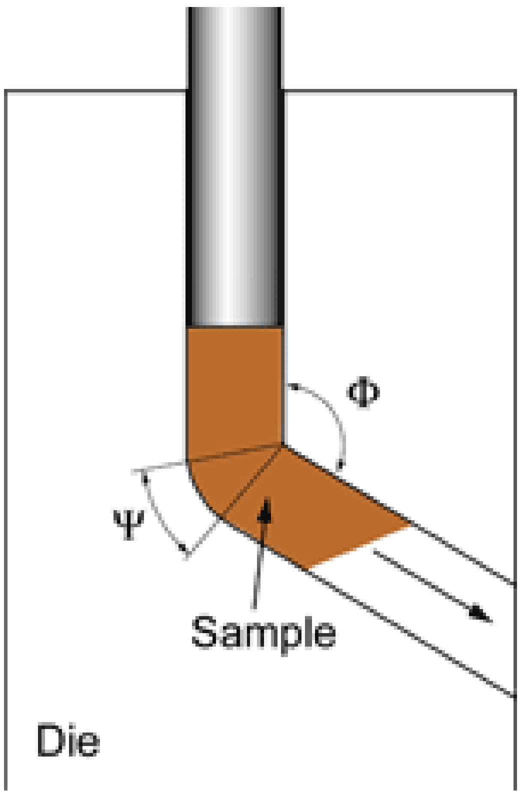
Severe Plastic Deformation (SPD) Processing

Equal Channel Angular Extrusion (ECAE)



Characteristics

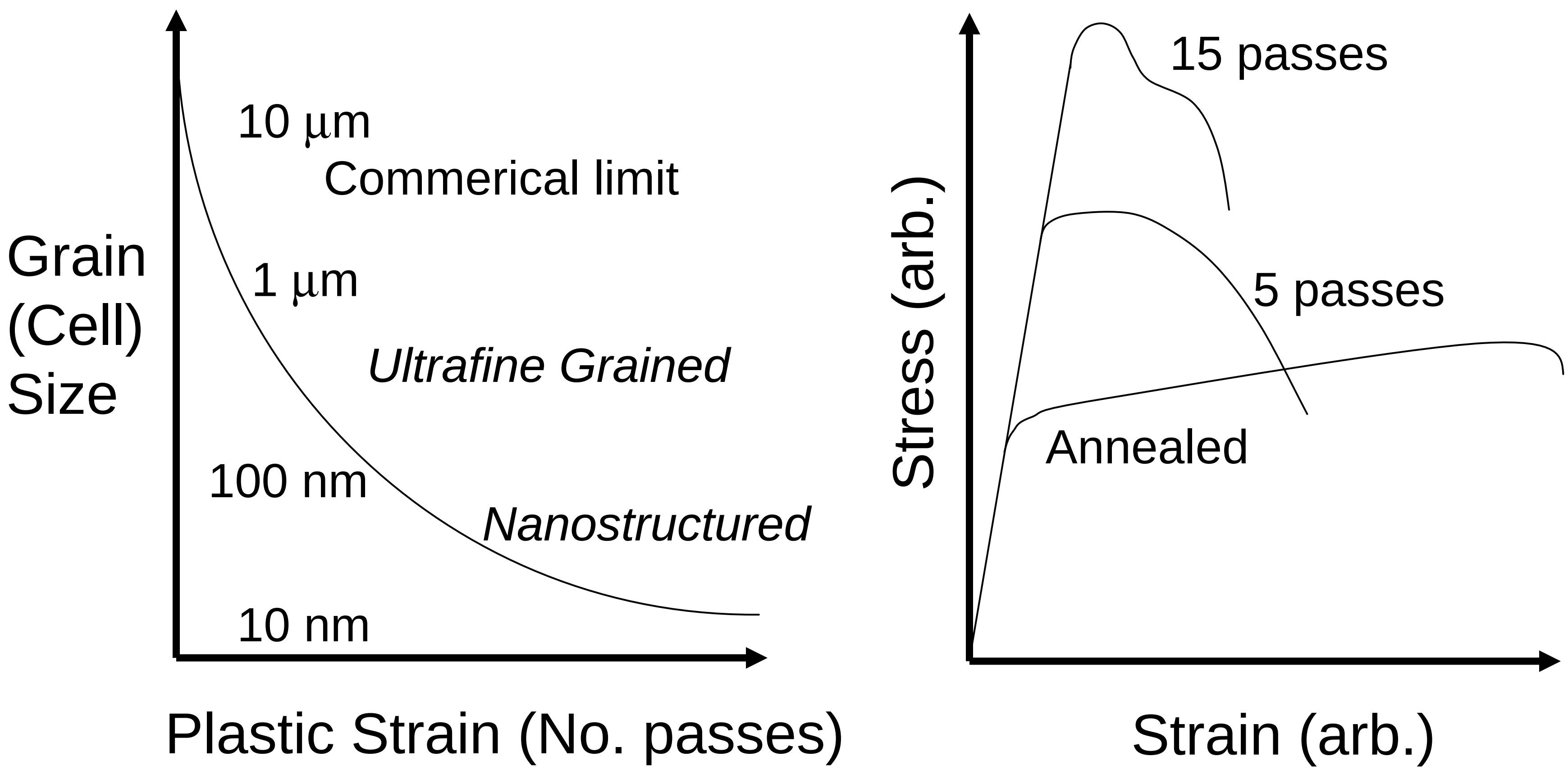
- Large plastic strains (γ = 0.5 per pass)
- No change in cross-section

Challenges

- Multi-stage deformation process
- Limited to low-medium strength alloys
- Strain is inhomogeneous

Structure-Properties Effects

Grain (substructure) refinement => Strengthening



Questions/Contexts

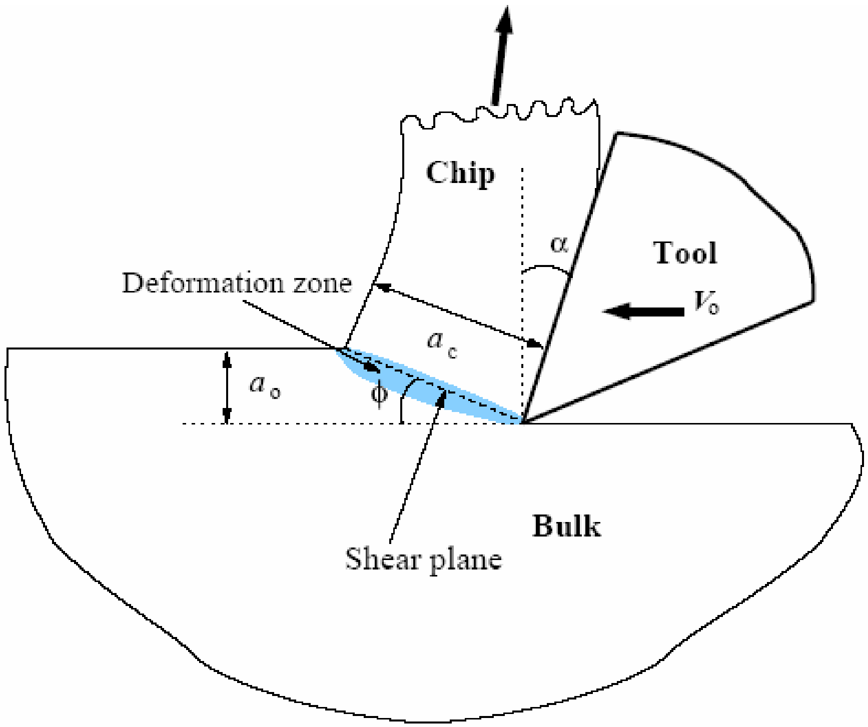
Applications

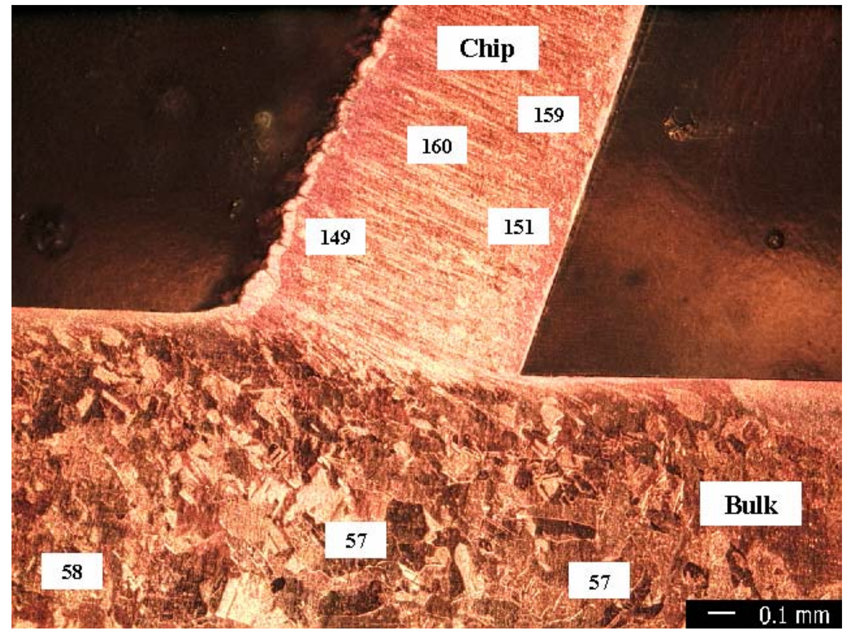
- Useful strengthening?
- Fracture toughness?
- Fatigue resistance?
- Wear?
- Thermal stability?

Physical Metallurgy

- Deformation mechanisms
- Strain path effects
- Strain rate - temperature
- Texture development
- Coarsening mechanisms

Machining as a method of SPD





OFHC Copper

Shear strain

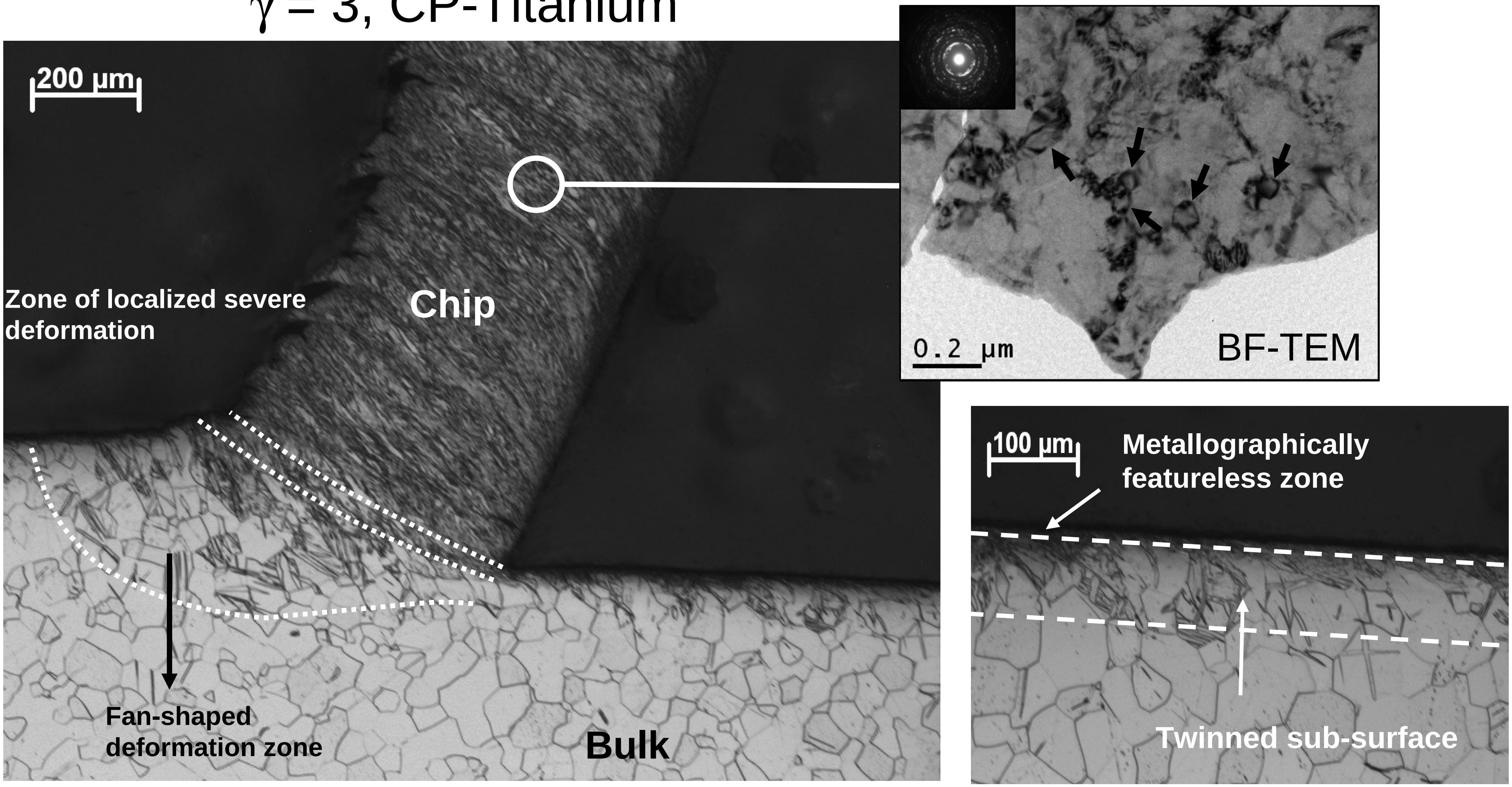
$$\gamma = \frac{\cos\alpha}{\sin\phi\cos(\phi-\alpha)}$$

γ = 1 to 15 in a single pass

T. Brown et.al., J. Mater. Res., 17-10, 2484, 2002

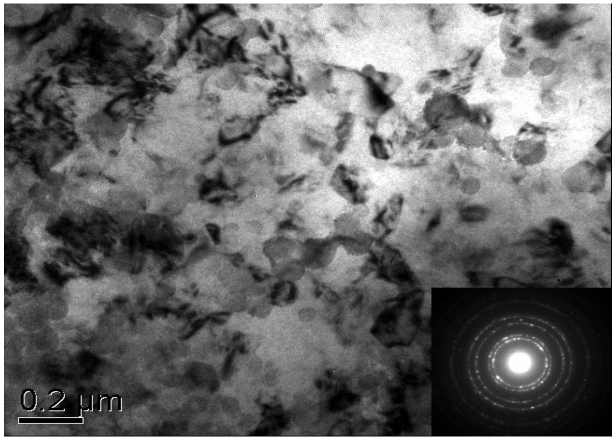
Deformation zone

γ = 3, CP-Titanium

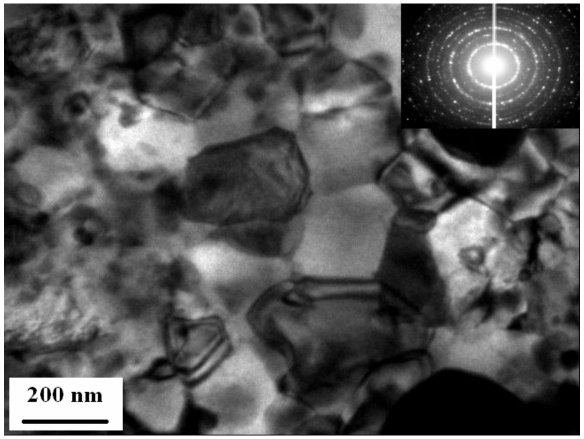


M. R. Shankar et. al., Acta Mater., 54, 3691, 2006

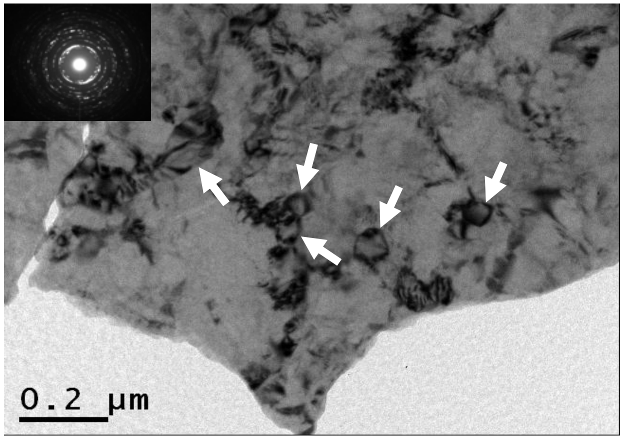
Ultrafine grained alloy microstructures



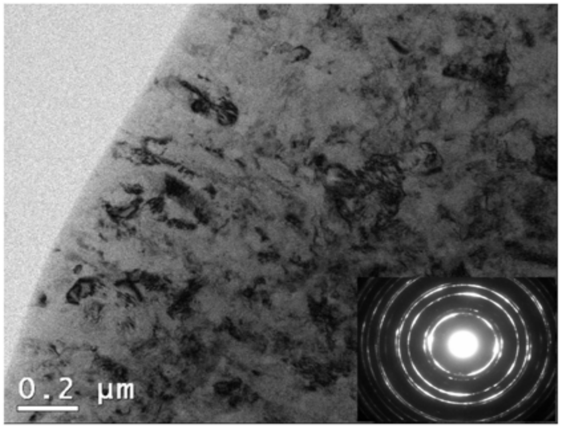
Al6061-T6, grain size: 75 nm



52100 steel, grain size: 330 nm

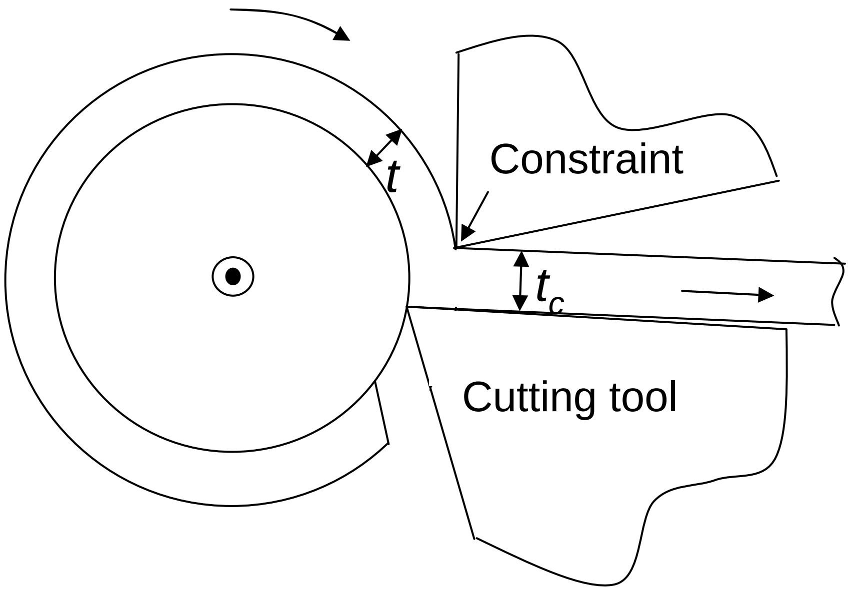


Ti, grain size: 90 nm



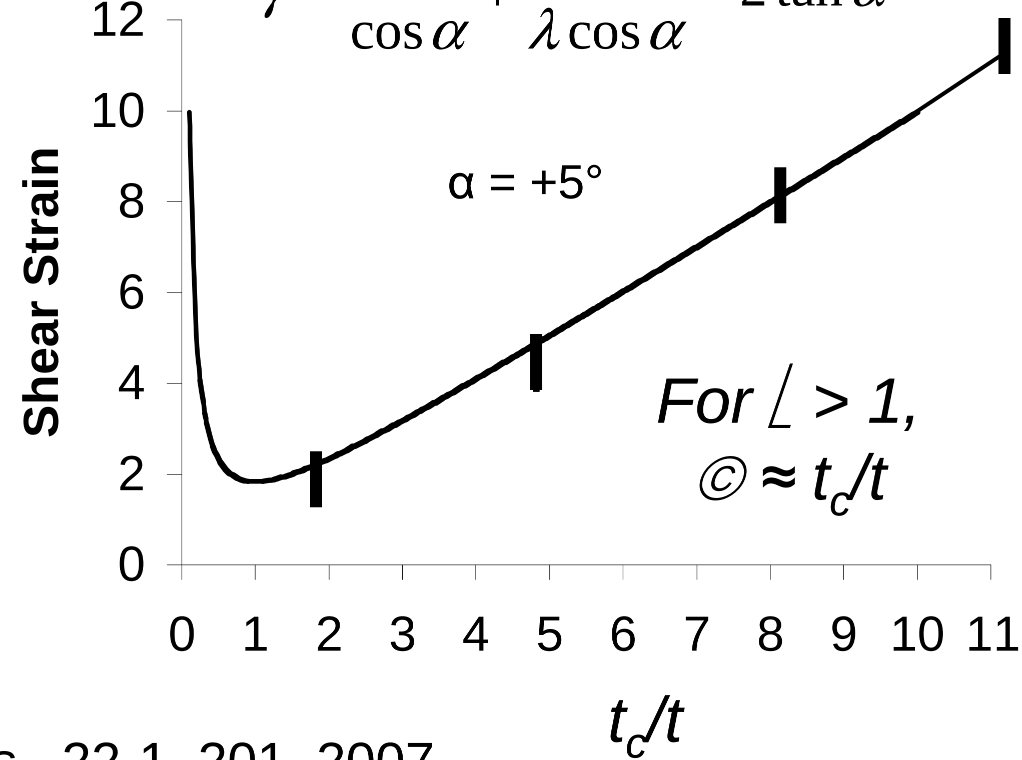
Inconel-718, grain size: 90 nm

Large strain extrusion machining (LSEM)



Upper bound model

$$\gamma = \frac{\lambda}{\cos\alpha} + \frac{1}{\lambda\cos\alpha} - 2\tan\alpha$$

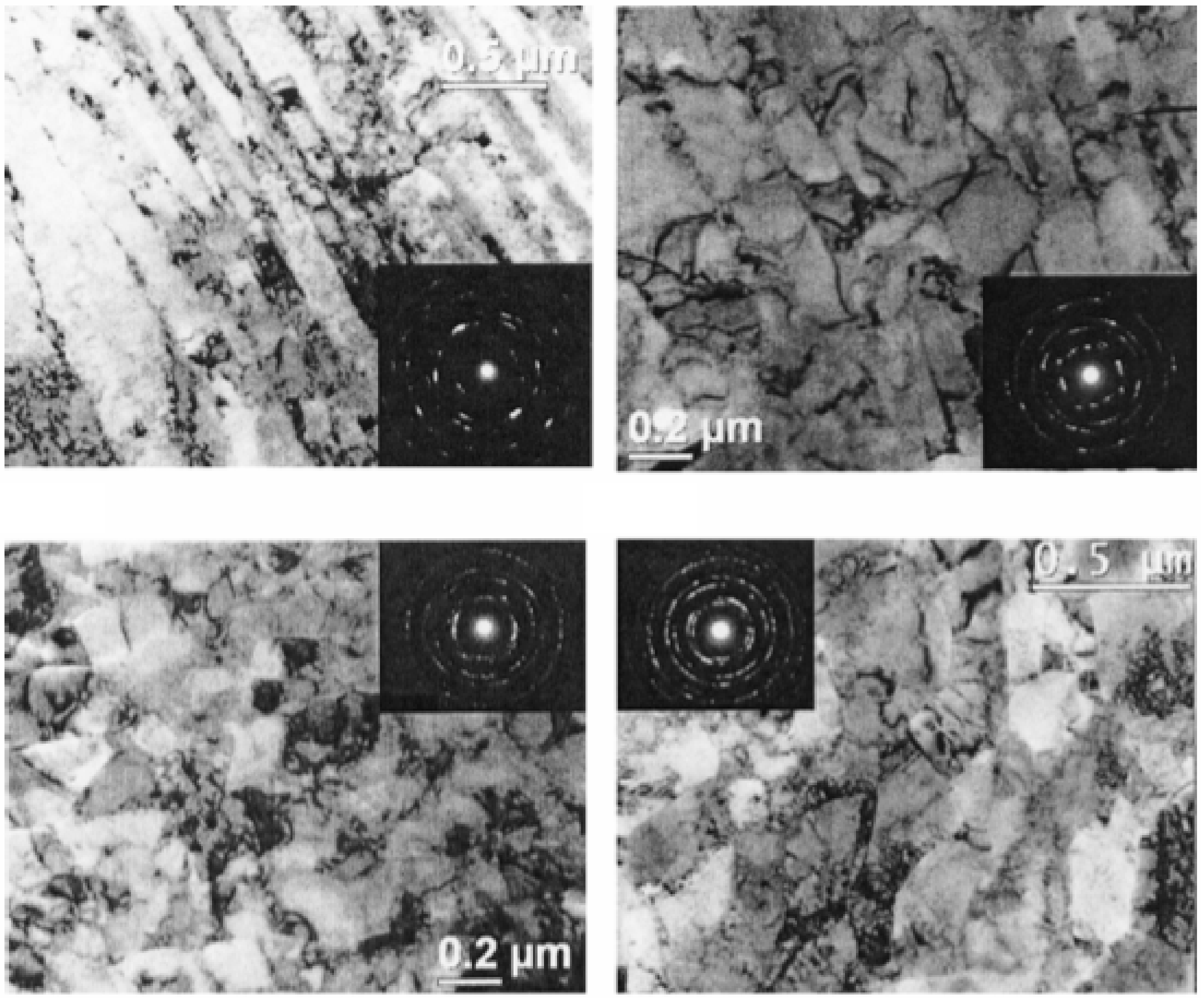


W. Moscoso et.al., J.Mater. Res., 22-1, 201, 2007

Microstructure with strain

γ = 2.2

γ = 4.3



OFHC

Copper

γ = 7.4

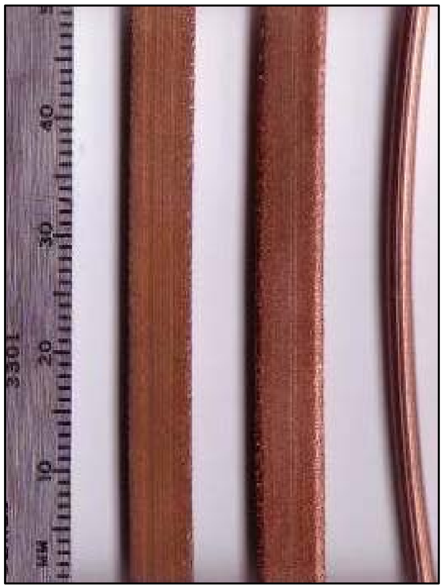
γ = 11

GS ~ 250 nm

GS ~ 250 nm

Bulk ultrafine grained materials by LSEM

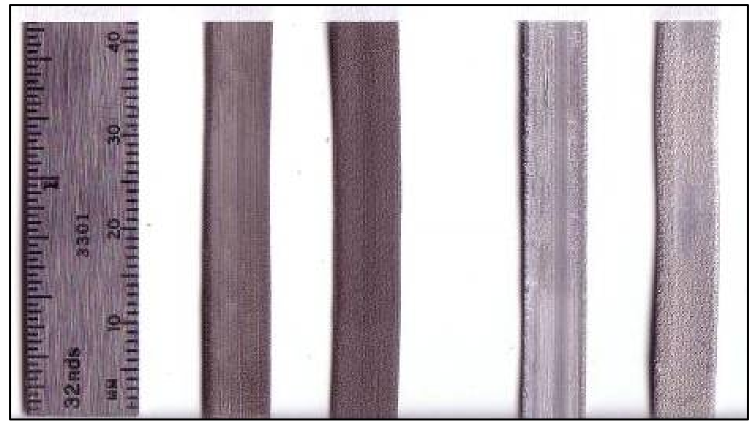
Copper



foil sheet rod

1 cm

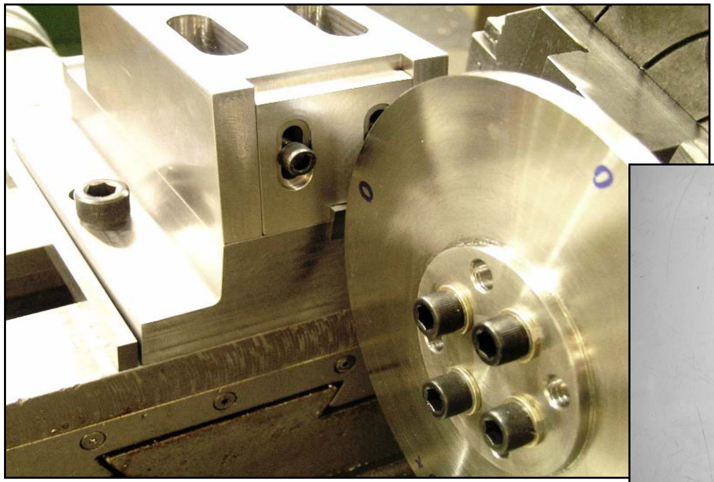
Titanium Al6061T6



Tantalum 1 inch Copper

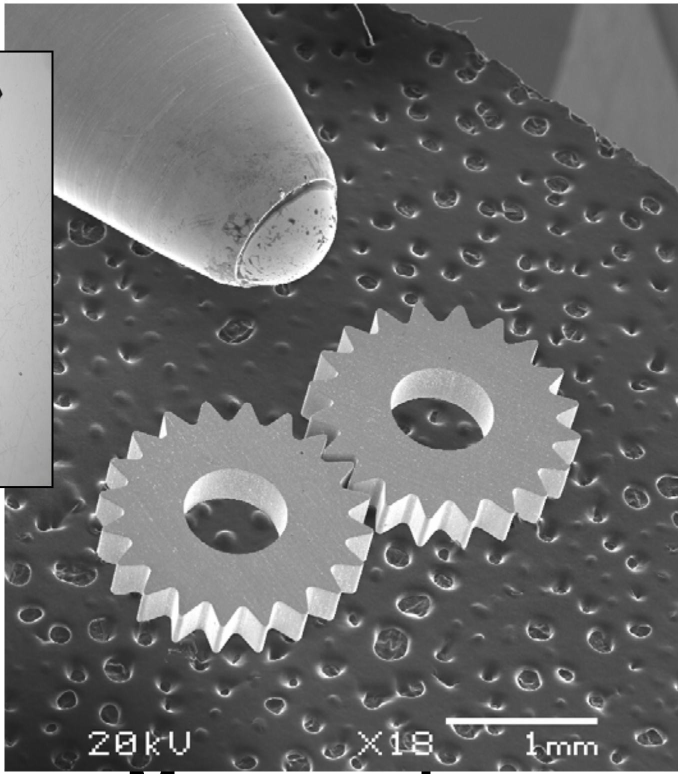
plate

Micro/Meso scale components



Large-Strain Extrusion Machining

Bulk Nano-Inconel 718

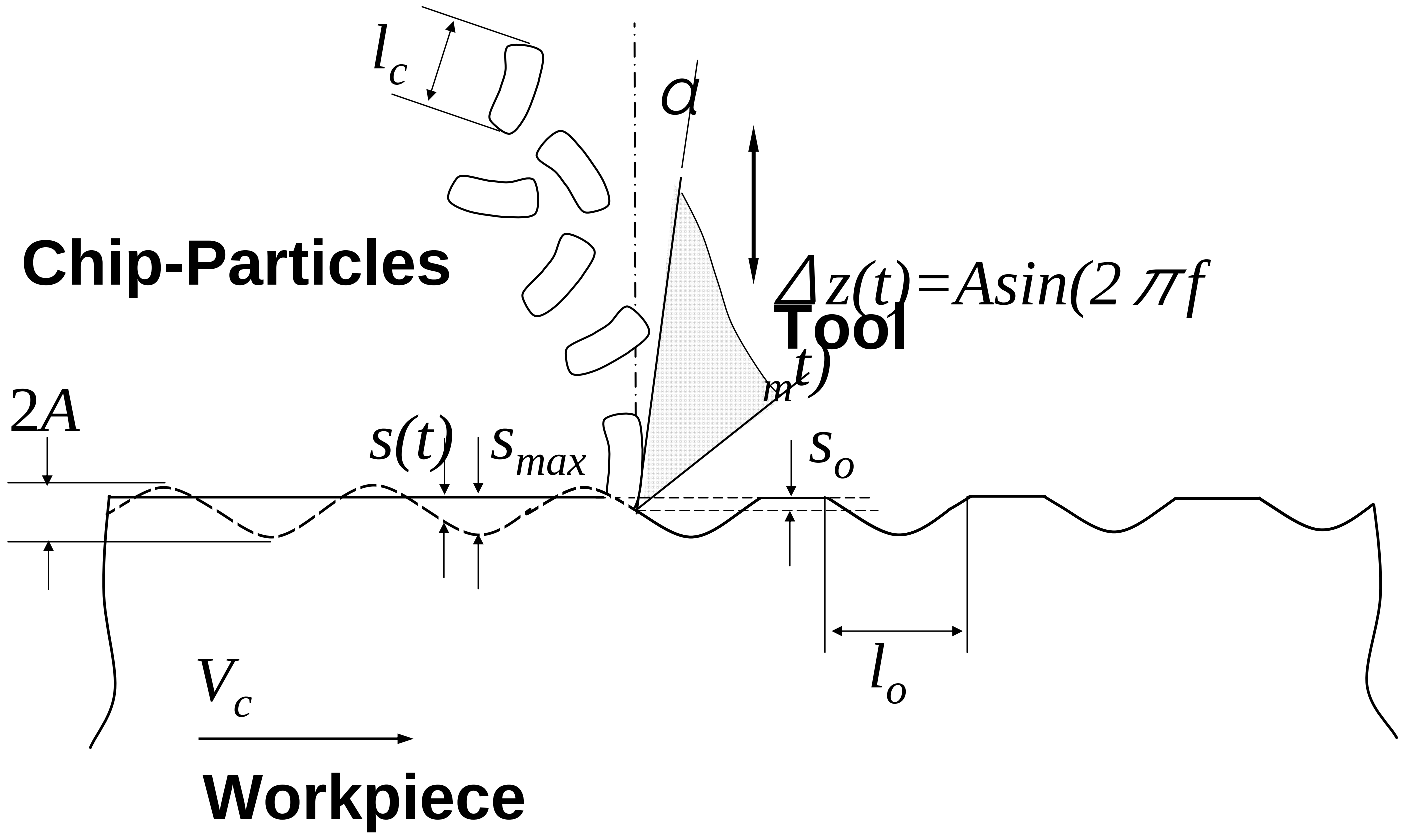


Meso-scale gears via EDM

Purdue/Sandia Collaboration

Direct Particle Production

Modulation-assisted machining (MAM)

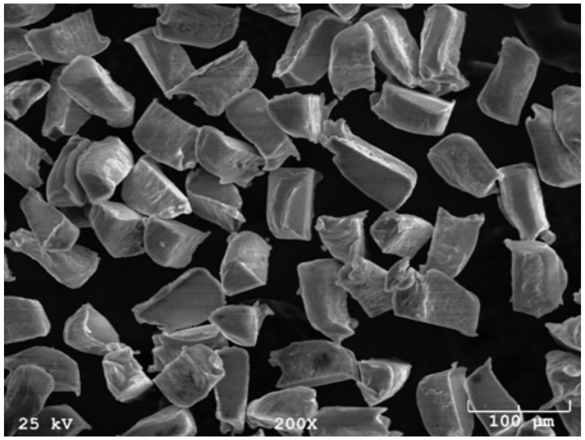


J. B. Mann, C. Saldana et al., Scrip. Mater., accepted July 2007

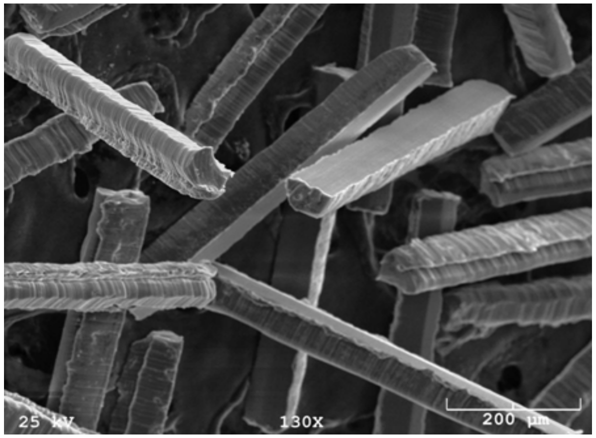
Particle morphology and size control

Al 6061-T6

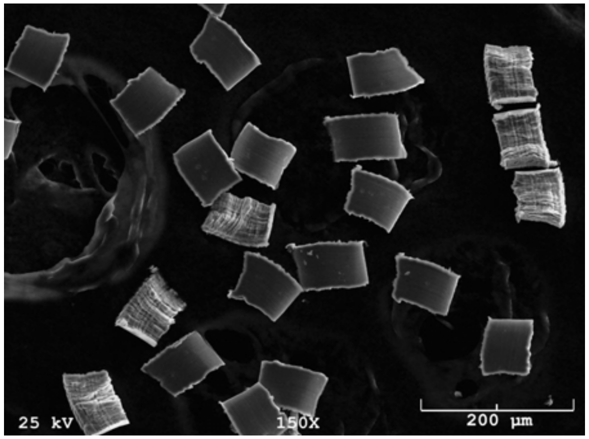
Equiaxed



Needle/Fiber



Platelet



- Unprecedented control of particle shape
- Extremely tight particle size distributions ($\sigma < 3\%$)
- SPD >> UFG structure in particles (50% harder than bulk -T6)
- Process is intrinsically scaleable

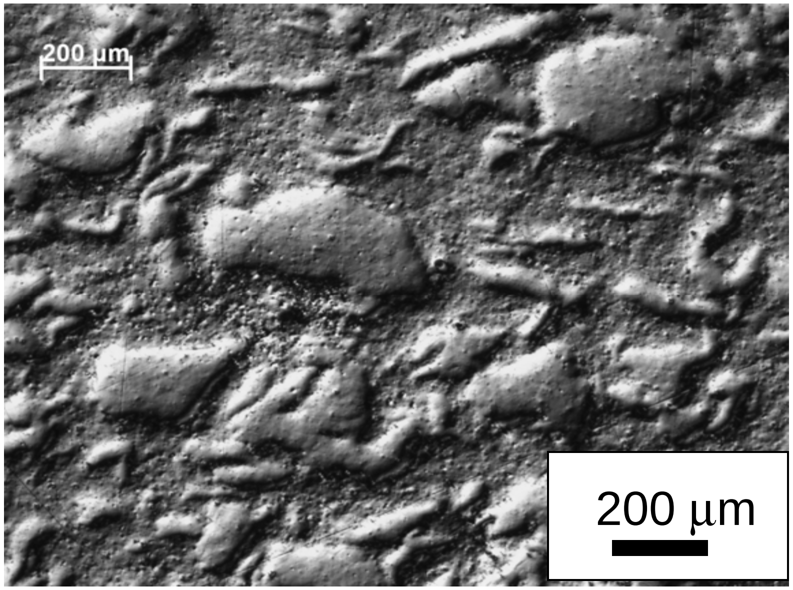
Low-Temperature Consolidation

Powder Extrusion

6061-T6 chip particles + pure Al

Extrusion ratio = 10, room temp.

Relative density = 97%

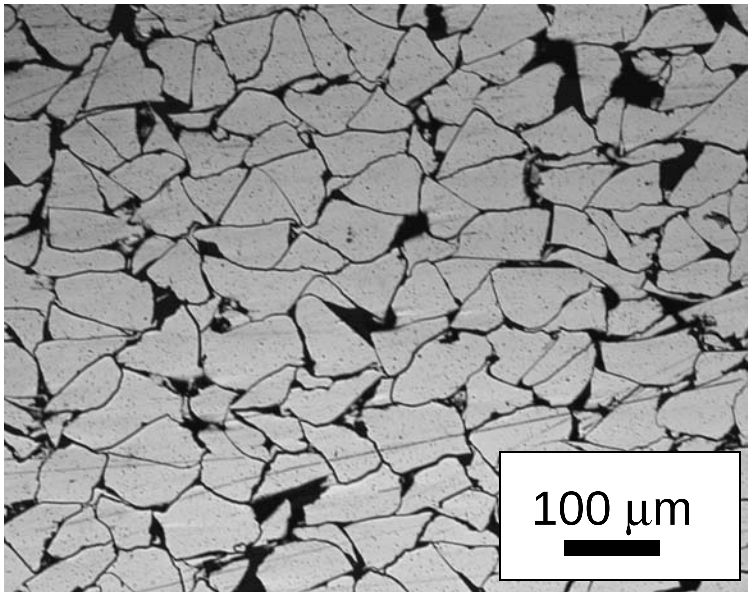


Epoxy-bonding

6061-T6 MAM particles + epoxy

Die pressed @ 800 MPa

>92% metal composites



Current Applications Focus

- High-strength, lightweight structural components

  e.g., Al 6061-T6, CP-Ti, Ti-6Al-4V

- Enhanced wear and fatigue resistance of steels

  e.g., austenitic stainless

- Enhanced thermal stability

  e.g., Al-6061-T6, IN-718

Advantages of machining for SPD

- Bulk, “chip,” and powder forms all possible
- Simple geometry of deformation
- Large strains in a single pass of the tool
- Applicability to a wide variety of materials

Even high strength, low ductility materials can be subjected to SPD at ambient temperature

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